§5. Required Accuracy of Inductance Measurement for Current Imbalance Phenomena

Yamaguchi, S.,
Shimada, R. (Tokyo Institute of Technology)

The cable of the superconducting magnet is composed of nine insulated strands. The material of the superconductor is NbTi, and the parameters of the coil bobbin, the strand and the cable of the magnet are listed in Table 1. The shunt resistor is used to measure the current and is the order of sub-hundred μΩ. Each shunt resistor circuit is measured to connect the dc power supply externally. The error of the measurement is less than 1 μΩ, therefore, the relative error is almost less than 1%[5].

Table 1, Parameters of Coil

Turn number and Coil Bobbin	
number of turn	149
diameter(mm)	376
length(mm)	110
Strand	
diameter(mm)	0.354
number of filament	187
filament diameter(mr	15.7
matrix	Cu-30%Ni/NbTi:1.1
Cable	
primary pitch	28
secondary pitch	44
twist	SS

The inductance matrix elements are measured by using a high precision LCR-meter. The LCR-meter was connected to the personal computer through GP/IB. Since we measured each matrix element 100 times and took an average of the data and estimated the error of the measurement and the direct output accuracy of the LCR-meter is 5 digits, the total accuracy of the measurement is 6 digits statistically. The measurements had been done for 20Hz, 100Hz and 1000Hz, and the inductance matrix are not same completely, but the differences are within 1%. The average element of the matrix is around 11.7 mH and the average error of the measurement is 0.5 μH, therefore the accuracy of the measurement is almost 5 digits.

After we measured the resistances of the shunt resistors and the inductance matrix, the current distribution is calculated to solve the circuit equations. The circuit equations are given by

$$(i\omega L_{ij} + R_{ij})\, \mathrm{I}_j = \mathrm{V}_i \qquad (1)$$

where ω is the frequency, L_{ij} is the inductance matrix, R_{ij} is the resistance matrix, I_j is the current vector and V_i is the external applied voltage vector.

We can obtain the current distributions of the strands to solve Equation (1). Since the electric circuits are coupled with each other strongly, the inductance matrix is almost singular and high precision calculation is needed. We used the ™Mathematica. The calculation accuracy is 60 digits in our case. The results are shown in Figs. 1 and 2. Figure 1 shows the function of normalized amplitude of the current versus frequency. There are nine circuits, and the averages

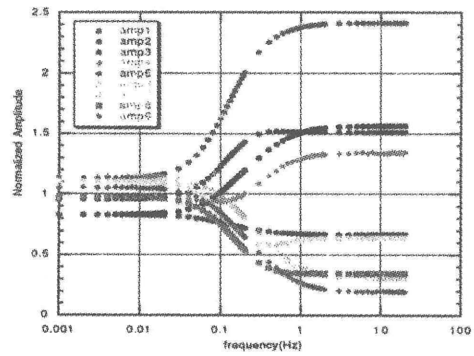

Fig. 1, Calculation result of the normalized amplitudes for the measured inductance matrix.

of the current amplitudes are unity in each frequency, and for example "amp1" means the current of the channel 1 in the figure. The amplitudes are changing from 0.01 Hz to 1 Hz along the resistance and inductance matrix. Figure 2 shows phase of the each strand current and "phase1" means the phase of the channel 1.

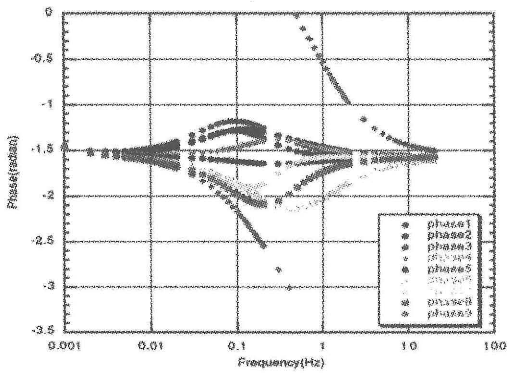

Fig. 2, Calculation result of the phase differences for the measured inductance matrix

These calculation results are compared with the experimental results that were measured the current directly, and they were matched well and reported and discussed in references 1 and 2.

References

1) A. Ninomiya et al, "Relation between impedance distribution and current imbalance in an insulated multi-strands superconducting cable conductor", submitted to *IEEE Trans.* Applied Superconduct.

2) T. Ishigohka, A. Ninomiya, S. Yamaguchi, I. Nomura, T. Sato, S. Hanai, Y. Hasegawa, H. Okumura, Ryu. Shimada, "Effect of impedance distribution on current imbalance in insulated multi-stranded superconducting conductor", *IEEE Trans.*, Appl. Superconduct., vol. 10, 2000, pp.1216-1219.